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Training for Night Operations – Research Challenges and Opportunities

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For millennia, planners of military operations have used the cover of darkness to advantage to prosecute vitally important missions. A majority of critically important missions now occur when darkness provides a measure of covertness. Those who are properly trained and equipped to operate at night will possess a tactical advantage over those who are not similarly prepared. Training environments providing credible representation of the night environment and associated effects are vital to help prepare Warfighters for tactical success in night operations, yet night training opportunities often are limited. A survey of all exhibits at a premier training and simulation conference in 2011 revealed that only 2.5% showcased anything that represented the night environment and/or the associated unique effects. This suggests that development of products for training night operations receives relatively little attention despite the number and criticality of missions that may occur during darkness. To address this apparent imbalance, this paper briefly reviews technical aids commonly used by Warfighters during night operations, and examines simulate vs stimulate approaches and tradeoffs in night training simulator environments. The paper then focuses on research challenges and opportunities associated with creating credible virtual and constructive night training environments, with a discussion of equipment, networked simulations, essential representation effects, and standards.

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Introduction

For millennia, planners of military operations have used the cover of darkness to advantage to prosecute vitally important missions. Literary accounts tell of the Greeks' fruitless ten-year siege of Troy, and their eventual stratagem of building a large wooden horse with a force of men hidden inside, leaving it outside the city gates, and ostensibly abandoning the siege and sailing away. After the Trojans pull the horse into their city as a trophy, the hidden force exits the horse that night and opens the city gates for the Greek army, which sailed back also under cover of darkness. More recent examples include the WW-II Allied invasion of Normandy, which began during darkness, and night operations mounted by the Soviet Red Army to maintain pressure on over-extended German forces during the Battle of Stalingrad; based on lessons bitterly learned, Russian military doctrine to the current day explicitly recognizes the value of night operations, particularly in an offensive role [1]. Contemporary examples of night operations include publicized missions in southwest Asia and eastern Africa. Arguably, a majority of critically important missions now occur when darkness provides a measure of covertness. Those who are properly trained and equipped to operate at night will possess a tactical advantage over those who are not similarly prepared.

The 2009 Capstone Concept for Joint Operations [2] articulates the need "to effectively and efficiently prepare future training audiences … for full spectrum operations anywhere in the world" and for "a joint force with improved capability and capacity to operate covertly and clandestinely." The 2010 DoD Strategic Plan for the Next Generation of Training [3] states that "the specific time, location and form of any particular challenge will be practically impossible to predict, at least in time to develop forces specifically for that threat" and further states that "the long-term objective is to produce an immersive training environment … [with] sufficient level of technical and operational realism." Given that full-spectrum operations continue 24 hours per day, operational realism for training by definition should include the night environment.

A survey of all 441 exhibitors at a premier training and simulation conference [4] in 2011 revealed that 115 exhibited visuals intended for use in training environments, but only 11 exhibitors or 2.5% showcased any visuals which represented the night environment, even if only still images; see Figure 1. Tools for training night operations may not necessarily be easy to demonstrate in a brightly-lit exhibit hall, but training for night operations seems to receive comparatively less attention from the community responsible for developing training tools. This document attempts to address this imbalance by describing approaches currently used in night operations training simulators, current gaps and challenges, and research opportunities.

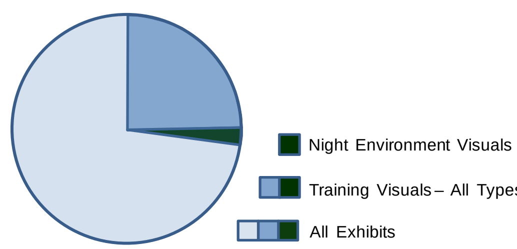

Figure 1. 2011 Training and Simulation Conference Exhibits and Visuals by Type

Night Operations Tools and Training Approaches

Compared to daytime operations, Warfighters in many night operational domains depend more heavily on sensor systems and technical aids of various types for information upon which they base their decisions. Such technical aids may include electro-optical imagers such as night vision goggles (NVGs), airborne forward-looking infrared (FLIR), ground-based thermal imagers, laser designators, or various combinations of these for the purpose of presenting to the Warfighter some sort of rendered image or cueing of the area of interest. The technical characteristics of these aids, such as resolution, field of view, bandwidth, or spectral emission and/or response, affect the user's perception of the environment, so it is important that such technical characteristics are credibly duplicated in the training environment so personnel can understand them in preparation for maximally benefitting from them while minimizing effects associated with their limitations.

Training for night operations currently occurs most commonly on live ranges. However, due to legal, ethical and/or practical constraints, live range opportunities and exposure to some effects essential for trainees' experience and currency may not be available. Training gaps can result, at the very least leaving Warfighters inadequately prepared; some gaps have been implicated in night mishaps resulting in loss of life [5]. If properly implemented, training simulator environments may provide exposure to many such effects and address some of these gaps.

Credible training simulator environments for different domains require different types and quantities of entities and effects. For example, some effects such as the appearance of missile launches, appropriate for creating credible training for night air operations, will differ from effects such as the appearance of vehicle lights appropriate for training night surface operations. Based on the origin of some of these effects in the real world, and the domain and type of training to be accomplished, a stimulate approach to the night training environment may be the method of choice; for others, a simulate approach may be the best or only option available. Both approaches are described in this document. The underlying assumption for both approaches is that credible-looking simulated scene imagery visible to the unaided eye is projected or otherwise presented on one or several screens, and that for practical and economic reasons a training environment (including projectors) usable for both day and night training is desirable.

All simulator environments for training night operations are just that: simulations. Either real or simulated imaging devices may be used in such environments. Simulated imagery that "looks real" is rendered (e.g., computer-generated) from stored scene file models, using either a subjective or a deterministic approach. In a subjective approach, imagery captured from sensor(s) under a variety of representative real-world conditions is used as a reference while pre-adjusting the rendering system, often with guidance from a subject matter expert (SME), until the imagery subjectively "looks about right" (SLAR). In a deterministic approach, the real environment, sensor(s), image generator (IG) and display system have been measured and physically modeled beforehand. Data-based spectral emission characteristics of real-world surfaces or objects as well as atmospheric effects then quantitatively determine the appearance of the sensor display in the training environment; e.g., there is end-to-end quantitative traceability. The fidelity of imagery may be a key consideration when simulator certification is required for personnel to gain credit for training occurring in the simulator, which potentially may affect choosing between a SLAR or a deterministic approach. Accurate rendering of imagery from a newly-introduced sensor having unique characteristics may be a matter of plugging its performance model into a deterministic system, whereas significant iterative tweaking with SME guidance may be required to approach the "new SLAR" in a SLAR system.

"Stimulate Approach" Training Environments

In a stimulate approach night training environment, the same night vision goggles (NVGs) used in the operational environment are used to view simulated scene imagery presented on the screen(s) in the training environment; the stimulate approach thus is a sensor-in-the-loop configuration with NVGs stimulated by the same scene imagery viewed by the unaided eye. The trainee simply aims their NVG at any area of interest within the entire scene presented on the screen. Use of real NVGs in the training environment offers the advantage of absolute physical fidelity of the NVG, and avoids the need for video cables or other tethers that are not present in the operational environment. Sensors other than NVGs generally cannot be used in stimulate approach environments.

The intensifier tubes in current NVGs respond to wavelengths between approximately 370 and 930 nanometers (nm), as shown in Figure 2. Minus blue filters are incorporated in NVGs used for airborne applications, limiting their response to wavelengths between roughly 650nm (deep red) and 930nm to allow them to be used in a cockpit without being adversely affected by illuminated cockpit displays. Some NVGs used for ground applications do not incorporate filtering and thus may respond to wavelengths across the entire radiant sensitivity band. In either case, in order to be

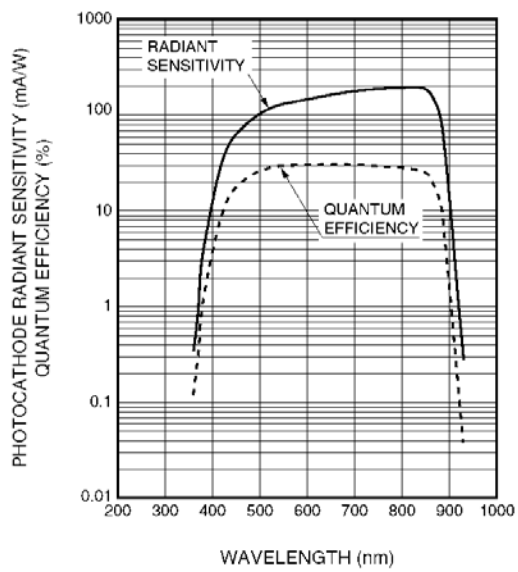

Figure 2. Radiant Sensitivity of Intensifiers Currently Used in Night Vision Goggles

sensed and intensified, the scene imagery must exhibit spectral emission that overlaps the band of NVG response; this is known as NVIS radiance. Both the amount of overlap and the proportion of NVIS radiance to visible energy are functions of - and will differ based upon - the projector/display technology and NVGs used.

NVGs are very sensitive to any light within their band of radiant sensitivity. The intensifier tubes in NVGs have a maximum gain (e.g., light amplification factor) of approximately 50,000, and incorporate circuitry that automatically reduces the gain as ambient light within their band of radiant sensitivity increases above a level roughly equivalent to quarter moon; as a result, the intensified image luminance is not allowed to exceed an upper limit of approximately 4 foot-Lamberts averaged across the entire field of view. Intensifier gain control is a function of the total input across the NVG instantaneous field of view, regardless of the source; as a result, only one or a few small but bright light sources may be sufficient to reduce gain and affect the entire image. As gain decreases, the luminance of other objects of interest appearing in the intensified image decreases and they become harder to see. Therefore, strict light discipline must be observed in stimulate approach training environments so projected scene imagery is the only significant source of energy stimulating the NVGs. Light from non-scene sources such as computer monitors, cockpit displays, equipment status lights, room lighting, exit signs, windows, etc., that may fall within the NVG field of view must be extinguished, blocked, filtered, or otherwise controlled so that it does not affect the intensifier gain and NVG image.

The dynamic range of energy present in the night environment due to natural illumination conditions alone spans three orders of magnitude from overcast starlight to full moon. When considering artificial light sources and illuminated objects, such as bright urban area lighting, laser pointer or designator beams, or munitions effects that also would plausibly be present in operational environments, this span of dynamic range can easily double or even triple to encompass a total of nine or ten orders of magnitude. Ideally a stimulate approach training environment would be capable of presenting scenes replicating the dynamic range present under any operational conditions, such that the NVGs would be stimulated to produce imagery matching that which they would produce in those operational conditions. Projector technology offering a contrast ratio of up to seven orders of magnitude [6] has recently been introduced, but at the current time no projector technology is available that has a dynamic range capability wide enough to match that of all real world conditions. When operating projectors near the extreme lower end of the brightness gamut to present a night scene, few brightness levels may remain and imagery may appear unrealistic. In such cases a neutral density filter may be introduced in front of a projector lens to allow it to operate at more normal settings and restore most or all brightness levels. Similar effects may be achieved with a front projection screen having low gain, although at the expense of day scene luminance. In addition to neutral density filtering, selective color filtering also may be introduced in front of a projector to achieve credible-appearing night scenes from both the NVG-aided and unaided perspectives. While easy to implement, filters are attenuators and their use will reduce the amount of energy reaching the screen, potentially reducing the effect of the projected scene on NVG gain. As a result, stimulated NVG imagery duplicating that seen in the real-world may be achievable only within limited dynamic ranges and lower illumination conditions.

Viewed scene content consists of both surface areas and point light sources. The spectral emission and reflectivity characteristics of many surfaces and sources have been measured and modeled, and significant work has been performed in developing methodologies to translate known radiance and reflectivity values of real-world objects under defined conditions into known luminance values (e.g, physics-based deterministic renderings) of scene elements in NVG intensified imagery [7]. Significant work also has been done in capitalizing on capabilities of commonly-employed projectors (e.g., addition of filtering) to support affordable solutions that provide imagery which appears credible through NVGs, but challenges remain in achieving rendering of extended surfaces and bright point sources that simultaneously appear credible to the unaided eye.

Bright point light sources, such as streetlamps and vehicle lights, are significant contributors to the wide dynamic range found in the night operational environment, and point sources commonly induce formation of a bright disc (halo) that surrounds each light point in an NVG image. Such halos can be important visual factors when prosecuting a mission and therefore should be included in a night training environment. Some recently-introduced projector technology [6], although expensive, can present light points that induce realistic-appearing halos in an NVG image. However, most commonly-employed projectors are not capable of presenting light points with sufficient intensity to induce halos of realistic density, particularly if projector filtering is used. Modeled halos may be generated to surround point light sources in the scene rendered by the IG. Because visible halos normally do not surround bright point light sources in the real world, modeled halos may be rendered only in dark red to minimize their visibility to the unaided eye while exploiting the high sensitivity of NVGs to red wavelengths. Healthy foliage which appears dark to the unaided eye also can appear bright in an NVG intensified image; as long as the scene luminance remains at a low level where human color perception is poor, foliage may similarly be rendered in dark red. Projectors recently have been developed which, in addition to visible channels, include a near-infrared channel dedicated to stimulating NVGs. Such projectors facilitate presentation of imagery that appears realistic both through NVGs and to the unaided eye, but cost may become a limiting factor if multiple such projectors are required to fill a large screen surface area (e.g., a dome) with imagery.

In an operational night environment the viewing distance between an NVG and the area of interest usually is infinity in optical terms, but in a training environment the distance between the NVG and the screen(s) being viewed is very short in comparison (e.g., often one or two meters). At close focus distances the objective lenses of NVGs exhibit a very shallow depth of field; when the lenses are adjusted for sharply-focused imagery at one close distance, imagery will be defocused - potentially severely - at slightly shorter and longer viewing distances. For example, with an NVG focused for sharpest acuity (Snellen 20/25) at a viewing distance of one meter, an increase of 30 centimeters in viewing distance will cause NVD-aided visual acuity (without refocusing) to degrade to worse than 20/100. A pinhole aperture, functioning as an f-stop, may be attached on the front of an NVG objective lens to increase the depth of field; however, the scene luminance then must be raised, potentially compromising its realism as seen by the unaided eye. An added pinhole aperture also constitutes an optical element not part of the original objective lens design, and it will degrade the NVG image resolution. NVG depth of field increases and defocus effects are reduced in environments with longer viewing and corresponding focus distances, but longer viewing distances and larger physical sizes of training environments may equate to higher costs. Therefore, intended training domains and scenarios, the optical characteristics of equipment to be used, and freedom of movement of trainees become tradeoff factors that must be examined.

Imaging equipment used in the military operational environment typically has excellent optics. When such equipment is used in a stimulate approach training environment, the net resolution obtained by the trainee typically is limited by the resolution of the scene imagery presented on the screen, which itself is a function of the projector(s), IG(s) and imagery database. Use of equipment having magnifying optics (e.g., binoculars) is not feasible in stimulate approach environments because the scene imagery projected on the screen will appear in the eyepieces simply as a magnified view of a small number of scene pixels; viewed resolution will decrease as the inverse square of the magnification factor.

The foregoing discussion has applied to unaided visible and NVG-aided imaging, but thermal imagers such as FLIR systems on aircraft and portable systems used by ground personnel also are employed in the operational environment. Use of an operational thermal imager in a stimulate approach training environment would require that all objects rendered in the scene include realistic thermal signatures in the band to which the thermal imager responds. Models of thermal signatures exist for many scenes and objects, but practical means currently do not exist for projecting or otherwise presenting thermal imagery on the screen(s) at a resolution useful for training. Thermal imaging equipment with magnifying optics also is not usable in stimulate approach environments for the reasons previously given. Physically emulated (e.g., “feels like, looks like”) thermal imagers presenting simulated imagery thus are the only option currently available. The aim of such imagers must be accurately tracked in real-time so the simulated imagery is registered (e.g., aligned) with other imagery simultaneously presented to the trainee. A cable or wireless data-link is required to transmit video of simulated imagery to the emulated device. The potential classification level of information in the training environment should be an early consideration when choosing the technology for transmitting signals to emulated devices; depending on its characteristics, gaining approval for use of a wireless data-link to transmit classified information may prove to be challenging.

Laser pointers and designators are commonly used in the ground and close air support environment, so their effects also should be realistically represented in the training environment. Operational laser devices have output power levels appropriate for targets at distances of up to several kilometers. Such lasers are not eye safe and cannot be used in indoor training environments. Physically emulated laser devices and simulation of their effects thus are the only option available. The position and aim of the emulated laser device must be accurately tracked in real-time, and a simulation of its beam with foreshortening appropriate from the trainee’s viewing perspective must be projected on the display screen at a wavelength to which NVGs respond, if appropriate for the laser device involved. The simulated beam also must be presented in the eyepiece of the simulated thermal imager or designator equipment if appropriate.

"Simulate Approach" Training Environments

In a night training environment using a simulate approach, all devices (including NVGs) employed by trainees are emulated (physically reproduced) and all imagery is simulated. Imagery is created either through deterministic (physics-based) rendering, or through subjective adjustment of the renderings (the SLAR approach), both as previously discussed. For highest training fidelity the physical configuration of the emulated equipment should match that of operational equipment, but means are required for conveying video and/or signals to and from the emulated equipment. The aim and orientation of all emulated imaging equipment also must be accurately tracked in real-time so the simulated sensor imagery is accurately aligned with unaided scenes simultaneously presented to the trainee. Provisions for signal transmission and real-time tracking will add physical features such as cables or modules not present on operational equipment; such features can be a concern for head-worn equipment such as NVGs, and should be as unobtrusive as possible. The anticipated classification level of information in the training environment needs to be an early consideration when choosing the technology used for transmitting signals to and from emulated devices; information security will trump physical fidelity.

Emulated imaging equipment usually does not require objective optics, so depth of field typically is not a factor and the distance between the equipment and the simulator screen typically has no effect on image focus. Similarly, because the emulated equipment is insensitive to light, strict light discipline need not be observed in stimulate approach training environments. Light originating from non-scene sources need not be extinguished or blocked, although it should be well-controlled to avoid creating visual distractions to trainees.

Because only simulated imagery is presented to trainees in simulate approach training environments, dynamic range effects for any night environment may be rendered in the simulated NVG imagery; the dynamic range limitations of projectors become a moot point. Significant research in physics-based simulation led to development of the Night Vision Training System (NVTS) [8] which was enabled by the SensorHost system [9] that performed all physics and NVG-specific computations for the IG. NVTS was successfully demonstrated in an F-16C training simulator at Air Force Research Laboratory in 2003. While SensorHost functions initially were performed using separate equipment connected to the IG, more recently the SensorHost functions have been integrated directly into IGs.

Simulator Fidelity

In the psychology literature, Hayes and Singer [10: 1] state that fidelity in the context of training systems may be defined as the level of realism that a simulation presents to the learner, this concept being an integral component in simulation because it defines "how similar a training situation must be, relative to the operational situation, in order to train most efficiently." They summarize fidelity as "…the degree of similarity between the training situation and the operational situation which is simulated. It is a two dimensional measurement of this similarity in terms of: (1) the physical characteristics, for example visual, spatial, kinesthetic, etc.; and (2) the functional characteristics, for example the informational, stimulus, and response options of the training situation." [10: 50] In a related vein, Gagné [11: 99] states, "close simulation has the aim of insuring high validity to the task presented to the trainer. It is not quite as easy as it sounds, though, to produce a highly valid measurement of performance by exact simulation of the operational environment." The primary reason for these seemingly counterintuitive findings lies with a fundamental understanding of how humans perceive and process sensory information. A discussion of human perception and processing of sensory information is beyond the scope of this document, but the end goal of training systems is increased effectiveness, so it seems fair to argue that training systems should be developed to maximize their effectiveness, not necessarily their fidelity (for which no published objective methods of measurement appear to exist).

A simulator does not need to provide an exact representation of the real world in order to provide effective training. In fact, some departure from exact realism may be necessary in order to provide the most effective training [10: 15; 11: 101]. Rendering systems based entirely on physics-based models and having deterministic end-to-end traceability can provide exact representation (e.g., fidelity), but such systems may be unnecessary for effective training and may be very difficult to implement in practice, particularly in the case of multiple networked systems encompassing different night domains and utilizing different IGs and imagery databases. This leads to the hypothesis that something less than full physics-based rendering, e.g., quasi-deterministic rendering, could provide simulation fidelity sufficient for effective training even though it would not provide an exact duplication of the operational environment.

Standards Research Opportunities

A set of standard reference surfaces and objects, lighting conditions, appropriate image characteristics for commonly-utilized sensor devices such as NVGs and thermal imagers, and measurement techniques could enable adjustment or calibration of any IG and the associated display system to achieve quasi-deterministic renderings. An example concept might be the SMPTE color chart [12; 13] used during the setup of video systems. Ideally, such a set of standards would be universally applicable to training simulators for all types of night operations. It seems reasonable to assume that such a set of standards would need to be bounded to some limited quantity that is easily dealt with, to facilitate adoption and utilization across simulator platforms and services. Given a bounded quantity, interpolation would be required, and the validity of the interpolations would depend on selection of the references and the chosen intervals between them. Research is needed to define such standard references and intervals, informed by those representation effects identified by the operational community as essential for training night operations. Such research also needs to define the minimum dynamic range in the night scene that still will allow immersive training for any night mission domain.

In distributed mission operations (DMO), live, virtual and constructive environments are data-linked together for training. Multiple simulator environments, each exposing trainees to virtual and/or constructive components of the overall DMO, may be networked together at one time, and it is possible that each of those simulator environments may employ a different type of IG, each with its own proprietary protocols. The common image generator interface (CIGI) [14] is an open-source non-proprietary simulation protocol for communication between a host device and an IG, intended to promote interoperability among IGs. CIGI is a useful foundation for advancing the standardization of commands between hosts and IGs, but it only goes so far, and does not define IG functional requirements, e.g., what happens in an IG's rendering process and the resulting appearance of the presented imagery. For DMO in which a simulate approach environment may be linked via network with a different environment using a stimulate approach and/or a different IG, common standards and methodologies are needed to ensure that the renderings of entities and effects visible to trainees in each environment appear credible to those trainees from their particular point of view, and are matched (e.g., synchronized) in luminance, radiance, temporal and spatial aspect appropriate to individual perspectives and locations, regardless of the IG type(s) employed at each location. Credible rendering of weather effects on sensor performance for each particular training environment's point of view also is needed. Such common standards would be a significant enabler for quasi-deterministic renderings across distributed mission training facilities. Research is needed to define such standards.

Representation Effects for Night Training

The joint terminal attack controller (JTAC) community has identified training for night close air support (CAS) as critical for tactical success and operations. Based on current doctrine and projected operations that will include both covert and force-on-force engagements between near-peers, the JTAC community has identified the following representation effects (assuming renderings of terrain, vegetation, buildings and vehicles) as essential in training environments for CAS at night:

- Parachute flares
- Laser marker and designator beams (ground- and air-based)
- Ambient illumination (moon phase and angle)
- Artillery flashes (outbound and incoming) and tracers
- Cultural lighting, vehicle lights, fires, explosions
- Dust and weather
- Night vision (including point source halo effects)
- Thermal targets imaging
- Strobes (friendly forces)
- Remotely Operated Video Enhanced Receiver (ROVER) video display

In addition to these effects or their close equivalents, the following representations also are appropriate for training the air component of night CAS:

- Rocket-propelled grenades and missile launches
- Aircraft external lighting (unaided and NVG-aided)

Research is needed to determine whether any representation effects in addition to the above are essential to constitute a list that could be universally applicable across services and across all types of night operations.

Wide Dynamic Range Technical Implementation

To this point the discussions in this document have focused on approaches, limitations and associated research opportunities in creating credible environments for training night operations. It also is appropriate to discuss means of achieving wide dynamic ranges in stimulate-approach environments.

Stimulate-approach environments for training night urban operations should be capable of stimulating NVGs such that intensifier gain varies from a maximum (e.g., 50,000) in no-moon austere area conditions to a minimum (e.g., 100 or less) in urban areas with streetlamps and vehicle lights. Dynamic range limits of current projectors make them incapable of inducing such realistic gain variations. In theory, with real-time tracking of the NVG aim, the brightness of projected scenes containing bright sources could be modulated to emulate the gain response of NVGs when exposed to such sources in the real world. However, modulation of scene brightness based on tracking would be effective only for one person at a time, which could be problematic in a multi-person environment. Such tracking also would require attachment of ancillary equipment to the NVGs which would negate some of the advantages of using real NVGs. Given that the same display projectors should be usable for both day and night scenes for sake of affordability, but projectors currently are not capable of producing scene dynamic ranges that encompass all effects needed for credible rendering of the night environment for training, separate means are desirable to create bright point light sources that appear credible to the unaided eye while also inducing appropriate gain variation and halo effects in NVG imagery.

Inexpensive, eye-safe (e.g., Class 1 or Class 2) laser pointers can project bright light points that induce realistic gain reduction and halo effects when viewed by NVGs. By combining the beams from red and green lasers with a simple optical combiner, a brilliant amber point results that appears credible as a parachute flare, vehicle headlamp or streetlight to the unaided eye. Such a combined laser approach has been successfully demonstrated in a JTAC training environment at 711HPW/RHA. Selective use of only a red or green laser also can allow realistic simulation of colored tracers used in actual field conditions. The output power of such lasers may be modulated through simple current limiting of the electrical power source. Steering of the laser beam may be accomplished by directing the output beam from the combiner optics into an X-Y mirrored galvanometer assembly; see Figure 3. A "point source engine" thus can be built using eye-safe red and green lasers, an optical beam combiner, and an X-Y mirrored galvanometer assembly. Available X-Y galvanometer movement assemblies [15], about the size of an orange and with low mass and inertia, are capable of high speed and accuracy appropriate for credible rendering of the movement effects of repetitious artillery rounds as seen from operationally realistic distances. Position encoding of the X and Y galvanometer axes, linked to the IG via a closed loop control system, can allow accurate alignment of the projected laser point with appropriate entities in the projected imagery.

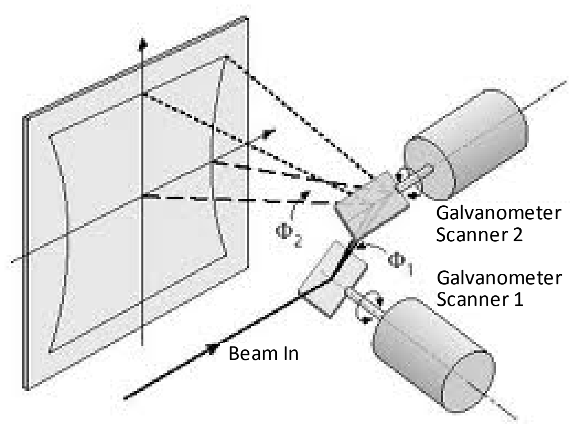

Figure 3. X-Y Mirrored Galvanometer Layout

Either a vector or raster scan approach may be used. When a vector approach is used, each bright light point appearing in the scene at any given time requires one point source engine; with a raster scan approach, one point source engine can project multiple bright light points in the scene. The number of bright light points required for credible training scenarios will differ depending on the domain and mission type. The minimum required number of point source engines thus will depend on the domain and mission, the scanning approach used, the size of the projection screen in the training environment, the distance and positioning of each engine with respect to the screen, and the angular coverage ("footprint") of each engine. Research is needed to determine the minimum number of bright point lights that simultaneously need to appear in a scene to achieve a credible training representation (scenario dependent).

The ability of a raster approach to project bright light points with sufficient energy to induce realistic gain and halo effects in NVGs is open to question. Assuming use of eye-safe lasers in a point source engine running in raster mode at 60Hz refresh rate, serving a screen area of $3.5m^2$, and with a projected bright light point located to a spatial precision of 1cm and filling $1cm^2$ of the screen area, the integrated energy per unit time per cm^2 of screen area will be more than six orders of magnitude lower than the constant-on energy from a vectored light point originating from the same laser sources. Expressed another way, the raster will dwell on inactive screen area more than 99.99% of the time. Research is needed to determine whether galvanometer speed is sufficient to avoid distracting flicker effects with a raster scan approach, and whether eye-safe lasers provide sufficient energy to induce gain variation and halo effects in NVGs. The perceived fidelity of raster and vector approaches also should be compared. If flicker effects with a raster approach prove problematic or spot energy is insufficient to induce gain and halo effects in NVGs, then a vector approach may be the only option. In this case the minimum number of bright point lights simultaneously appearing in a scene defines the number of point source engines required. With artful planning of training scenarios, the quantity of bright light points simultaneously appearing on the screen(s), and the corresponding point source engines, could be limited to a manageable number, e.g., perhaps four or five total.

Of the essential representation effects previously listed, the parachute flares, artillery flashes and tracers, cultural lighting, vehicle lights, fires, explosions, NVG halo effects, and strobes may be created using an overlay of the eye-safe laser points and conventional projected imagery or by the lasers alone. With appropriate calibration using the standards previously discussed, the resulting total dynamic range presented in the training environment could approach or match that existing under most reasonable real-world night conditions.

Summary of Research Needs and Opportunities

The following is a summary of research needs and opportunities, as previously described in this document, appropriate for creating credible training environments for night operations.

- Define domains, platforms/Mission Design Series, and mission types (in addition to JTAC) for which data should be collected on night representations required for credible realism and training experiences. Include in Mission-Essential Competency analyses.

- Define the minimum dynamic range in the night scene that still will allow immersive training for any night mission domain.

- Define a set of standard reference surfaces and objects, lighting conditions, appropriate image characteristics for commonly-utilized sensor devices such as NVGs and thermal imagers, and measurement techniques to enable adjustment or calibration of any IG and the associated display system to achieve quasi-deterministic renderings. Also define the intervals between such standard references. (The SMPTE color bar chart, as used for calibration of color video systems, might serve as an example concept.)

- Define common rendering standards, to ensure that the renderings of entities and effects visible to trainees in each environment appear credible to those trainees from their particular point of view, and are matched (e.g., synchronized) in luminance, radiance, temporal and spatial aspect appropriate to individual perspectives and locations, regardless of the IG type(s) employed at each location.

- Define standards to enable credible rendering of weather effects on sensor performance for each particular training environment's point of view.

- For laser pointer and designator beams, define methodologies to credibly simulate when using real NVGs. Also define methodologies to render credible sparkle/dust/ attenuation effects in the atmosphere.

- Investigate and define the required precision and associated technical means of simultaneously tracking, with six degrees of freedom, the individual locations and positions of multiple physically emulated devices within large working volumes. In parallel, define the bandwidth and range requirements for transmission of signals to and from all physically emulated devices used in the training environment. Consider both information security requirements and unobtrusiveness for physical fidelity purposes. Also consider both indoor standalone, indoor networked and outdoor training environments with LVC in DMO.

Research needs and opportunities summary, continued:

- For bright point light sources, define:
  - The minimum number that simultaneously need to appear in a scene for credible representation. This will vary depending on domain and scenario, and the domain/scenario having the largest number as its minimum requirement is the quantity of interest. And thus by extension, the minimum required quantity of point source engines.
  - With a raster scan approach, whether galvanometer speed is sufficient to avoid distracting flicker effects.
  - With a raster scan approach, whether eye-safe lasers provide sufficient energy at any point on the screen to induce gain variation and halo effects in NVGs.
  - Perceived fidelity, both unaided and NVG-aided, comparing vector and raster scan approaches.

Bibliography

1. Sasso, Claude R, Maj USA. *Leavenworth Paper No. 6, "Soviet Night Operations in World War II."* Combat Studies Institute, U.S.Army Command and General Staff College, Ft. Leavenworth, Kansas. December 1982. http://usacac.army.mil/cac2/cgsc/carl/resources/csi/Sasso/SASSO.asp

2. Capstone Concept for Joint Operations, v3.0. Washington D.C., Department of Defense, 2009.

3. Strategic Plan for the Next Generation of Training for the Department of Defense. Office of the Under Secretary of Defense (Personnel & Readiness), Readiness and Training Policy and Programs. 23 September 2010.

4. Interservice/Industry Training, Simulation and Education Conference (I/ITSEC) 2011 http://www.iitsec.org/about/Pages/HighlightsFromLastIITSEC.aspx

5. Accident Investigation Board Reports F-15E TN 90-0231, July 18, 2009 and F-16CM TN 89-2108, June 22, 2009; both available at http://www.acc.af.mil/aibreports/index.asp

6. http://www.barco.com/en/products-solutions/projectors/simulation-projectors/10-megapixel-lcos-training-and-simulation-projector.aspx

7. Clark, Jeff (2006). Physics-based Stimulation for Night Vision Goggle Simulation. AFRL-HE-AZ-TR-2006-0050, Mesa, AZ. USAF Research Laboratory.

8. Anderson, G.M. et al (2002). *Integration of a Legacy System With Night Vision Training System.* AFRL-HE-AZ-TR-2002-0069, Mesa, AZ. USAF Research Laboratory.

9. Renaissance Networking, Inc. *SensorHost v2.0 Software System Development* (Contract: F41624-97-D-5000, CDRL: A002, FOUO, distribution only as authorized by AFRL/HEA), Tempe, AZ: Renaissance Networks, September 15, 2003.

10. Hayes, R. T. and Singer, M. J. (1989). *Simulation Fidelity in Training System Design*, Springer-Verlag, New York.

11. Gagné, Robert M. Training Devices and Simulators: Some Research Issues, *American Psychologist*, 9: pp 95-107.

12. http://www.mediacollege.com/video/test-patterns/colour-bars-smpte.html

13. http://www.videouniversity.com/articles/color-bars-and-how-to-use-em/

14. http://cigi.sourceforge.net/

15. http://www.onestoplasershop.com/cambridge-6215-30k.htm